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THREE-DIMENSIONAL ELECTRICAL RESISTIVITY FOR DETECTION OF SUBSURFACE KARST ASSOCIATED WITH FRIESENHAHN CAVE

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Abstract

Electrical resistivity imaging techniques have proven to be an effective technological advancement for detecting subsurface karst features in carbonate formations. Numerous variables, such as electrode configurations, moisture conditions, carbonate lithology, and structure, can affect how effectively and accurately the generated images replicate actual underground features. This study investigates the electrical resistivity of Friesenhahn Cave and the surrounding strata and attempts to predict the morphology of what are believed to be extensions to the currently known single chamber of Friesenhahn Cave. Current observations within the known cave clearly show a collapsed entrance, which has been dated to the Pleistocene. Observations of water flow, as well as the collapse of sediments from sections of the cave floor, indicate a potentially significantly-sized additional passage extending beyond the known cave. Electrical resistivity results also provide an opportunity to determine the point of easiest access to the extension chambers so as to minimize the excavation efforts needed to obtain physical access to them from the existing cave. Assuming access to those chambers, physical measurements of the extension chambers will be used to confirm the results of the dipole-dipole array.

Introduction

An electrical resistivity survey was conducted at the Friesenhahn Cave in north San Antonio, Texas (Fig. 1). The purpose of the survey was to identify and evaluate potential karst features (i.e., caves and solution cavities) in the shallow subsurface (i.e., to depths of approximately 40 ft) that extend beyond the extent of the known cave. An electrical resistivity survey was performed because this technique can effectively delineate areas in the subsurface, where caves and solution cavities might be present.

The electrical contrasts between competent limestone, filled voids, and karst features can create conditions favorable for high-resolution electrical resistivity surveys to detect anomalies in the electrical properties of the subsurface. Air-filled voids, which can vary in size from caves (i.e., large enough for a person to enter) to solution cavities (i.e., sub-centimeter to approximately one meter in scale), can have a distinctly different electrical signature (e.g., more resistive) relative to the surrounding limestone. Clay-filled voids also have a distinctly different electrical signature (e.g., more conductive) relative to the surrounding limestone.

Given this diversity in the electrical signature exhibited by karst features, detection of karst features using electrical resistivity can be complicated (Green, et.al., 2013). General observations can be summarized as follows:

- Large air-filled voids typically appear as electrically resistive.
- Large water-filled voids typically appear as electrically conductive.
- Small air-filled voids can appear as either electrically resistive or conductive.
- Clay-filled voids can appear as electrically conductive.
- Clay-, water-, and air-filled voids may not have an electrical signature in the survey results if the void is not sufficiently large.
- Voids are recognizable in electrical survey results when a combination of electrical contrast between the void and the host rock, and the size of the void is sufficiently large. Smaller voids may be detected in cases where the electrical contrast is greater.

The key to these observations is that signatures of the features appear as anomalies when compared with the host rock, provided the host rock has a relatively uniform electrical signature. Subsurface electrical resistivity survey results of the known cave will be compared with areas adjacent to the known cave to indicate where additional cave passages might extend. These results will be verified by excavation and drilling. Survey results will guide excavation and drilling locations, where additional unknown cave passages have been indicated.

The electrical resistivity survey was conducted using a Syscal Pro electrical resistivity system (IRIS Instruments, Orleans, France). The electrical properties of the geologic section beneath the rectangular survey areas were modeled to a depth of approximately 12 m (40 ft). The measured resistivity data were inverted to provide an interpretation of the subsurface.

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Figure 1. Modern entrance shaft of Friesenhahn Cave, looking up the ladder.

Site Description

Friesenhahn Cave is located in northern Bexar County, Texas, west of US 281 and north of Stone Oak Boulevard (Fig. 2). The area is known for significant karst development and contains dozens of named caves as well as numerous unnamed sinkholes and unexplored cavities (Veni, 1988). Located within the Balcones fault zone, the cave appears to have developed adjacent to a fault plane. The cave initially formed as a phreatic chamber in the basal, nodular section of the Kainer Formation, Edwards Group. However, with the drop of the water table, the cave became subject to vadose zone processes, including significant calcite deposition.

The known portion of Friesenhahn Cave consists of a single, oval-shaped chamber, about 18 m long and 10 m wide, with a ceiling height of about 2.5 m (Fig. 3). Located about nine meters below the surface, the known chamber is accessed by a vertical shaft, approximately two meters in diameter, that was caused in part by solution and part by collapse. Narrow gaps (five to 10 cm wide) drop down approximately one meter along the edges of the cave floor walls. These openings appear to curve outward beyond view and beyond access. Significant volumes of water flow through these gaps during rain events, which adds further evidence of adjacent, yet-undiscovered chambers and a direct conduit to the aquifer.

Friesenhahn Cave is interpreted as having a paleo-entrance, now filled by natural debris comprised of breakdown and soils. The paleo-entrance, located at the northwest end of the Friesenhahn Cave,

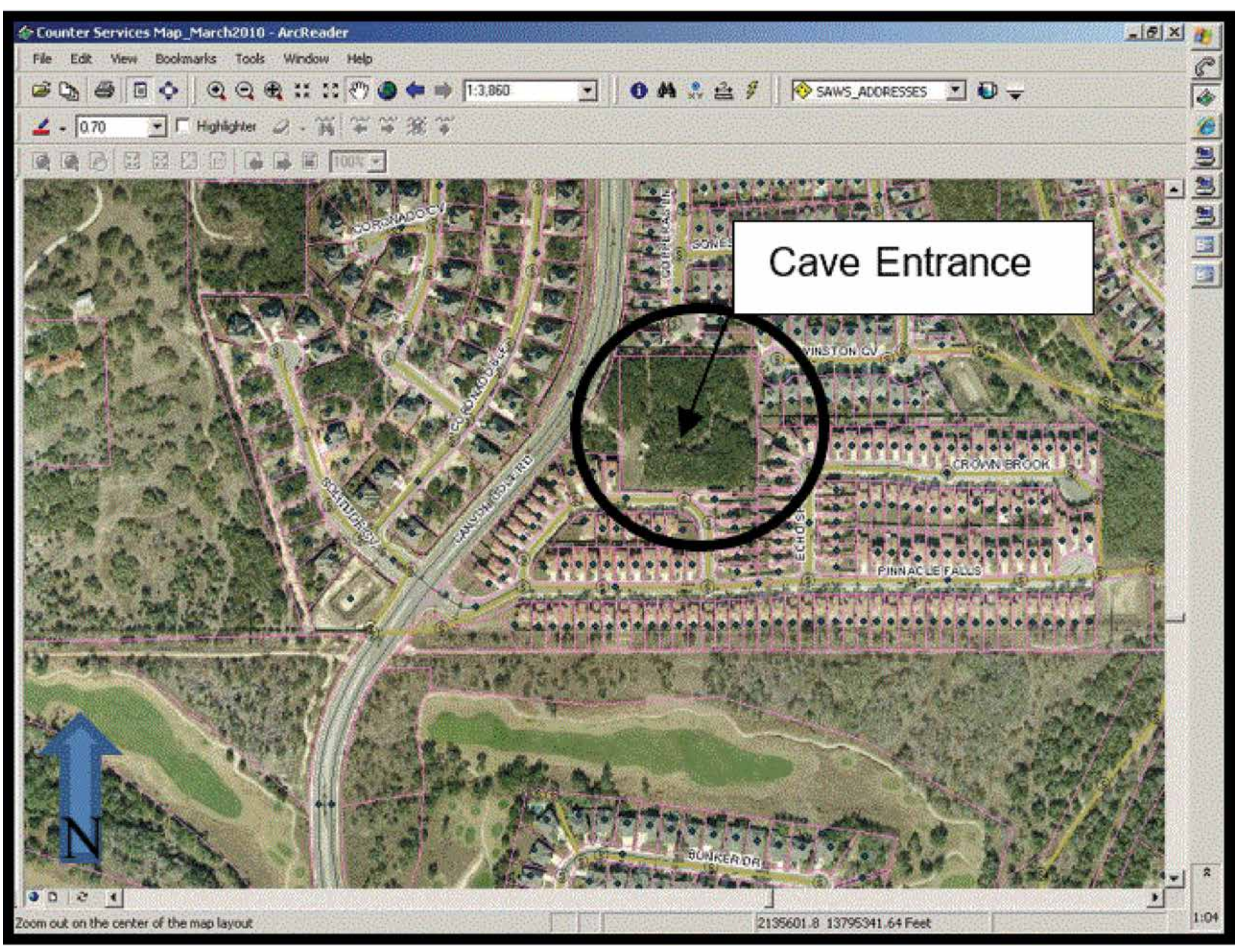

Figure 2. Friesenhahn Cave located on a small parcel, surrounded by residential development.

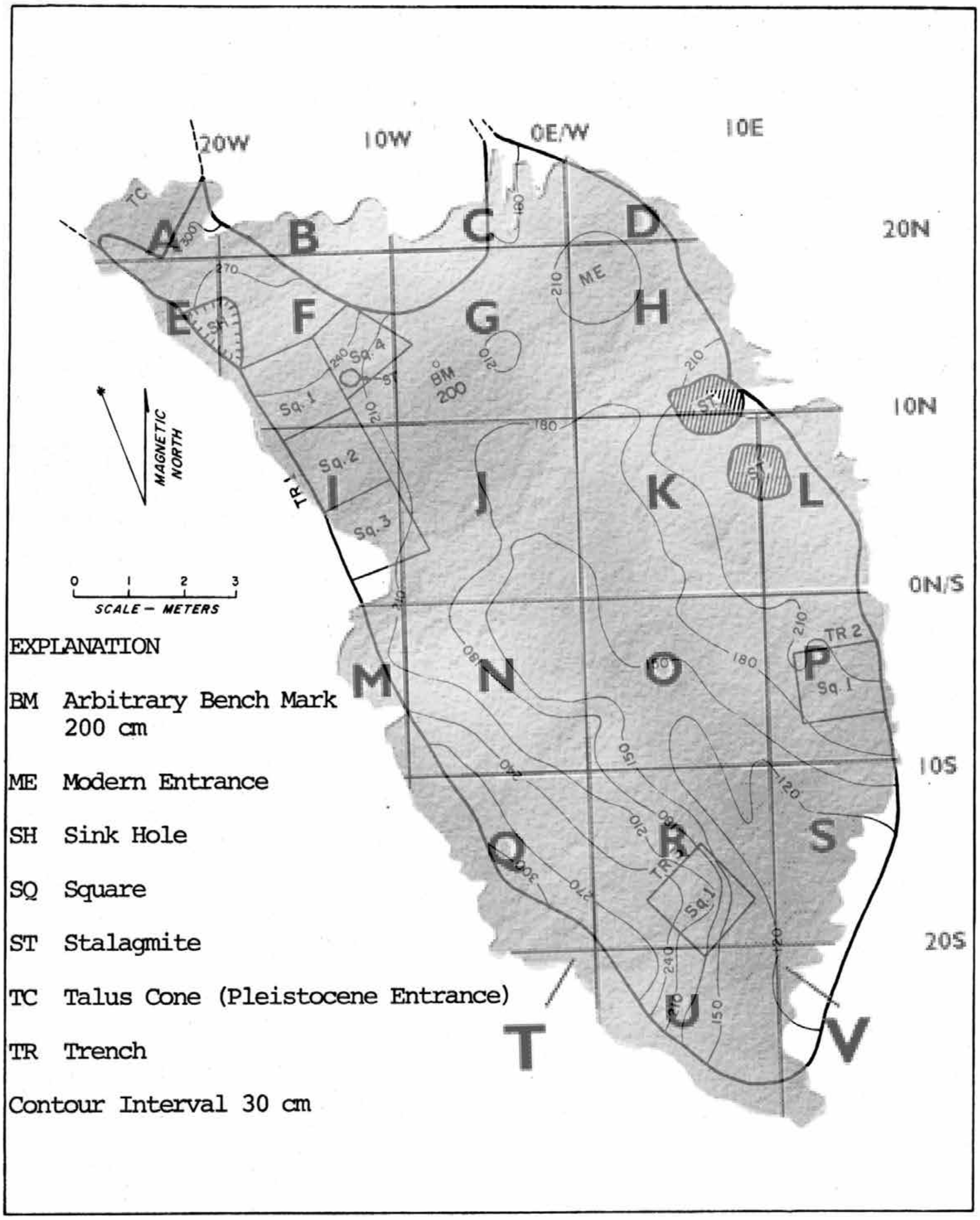

Figure 3. Map of Friesenhahn Cave (Graham, 1976).

has been frequently explored since its initial discovery in 1915. Notable are scientific expeditions by The University of Texas in 1949 and 1951, at the invitation of Mr. Alfred Friesenhahn (Milstead, 1956). Sediments within the main chamber of the cave have yielded thousands of bones from numerous vertebrate groups, including over 30 genera of mammals. In fact, Friesenhahn Cave has probably produced more significant fossils of Pleistocene vertebrates than any other site in North America, except LaBrea Tar Pits in California (Lundelius, 1967). Large deposits of unexhumed fossils can also be seen in the sediment and collapsed rock debris along the edges of the cave floor. In addition, surface collapse, at the north end of the main chamber, appears to block access to possible cavity extensions that conceivably could yield vertebrate fossils that utilized this site as a shelter earlier in the Pleistocene.

Survey Techniques

Three-dimensional electrical resistivity measurements were taken across four grids of 35 m by 55 m. The four grids overlapped by one electrode row in both the x and y directions with the vertex being located directly over the entrance shaft of Friesenhahn Cave. Final total combined grid size is 70 m by 110 m. Dipole- dipole electrical resistivity data were taken using a Syscal Pro Switch 96 electrical resistivity system (IRIS Instruments). The layout included a 12 by 8 electrode grid at 5 m spacing. Earth Imager 3D (Advanced Geosciences Inc., Austin, TX) was used for data inversion.

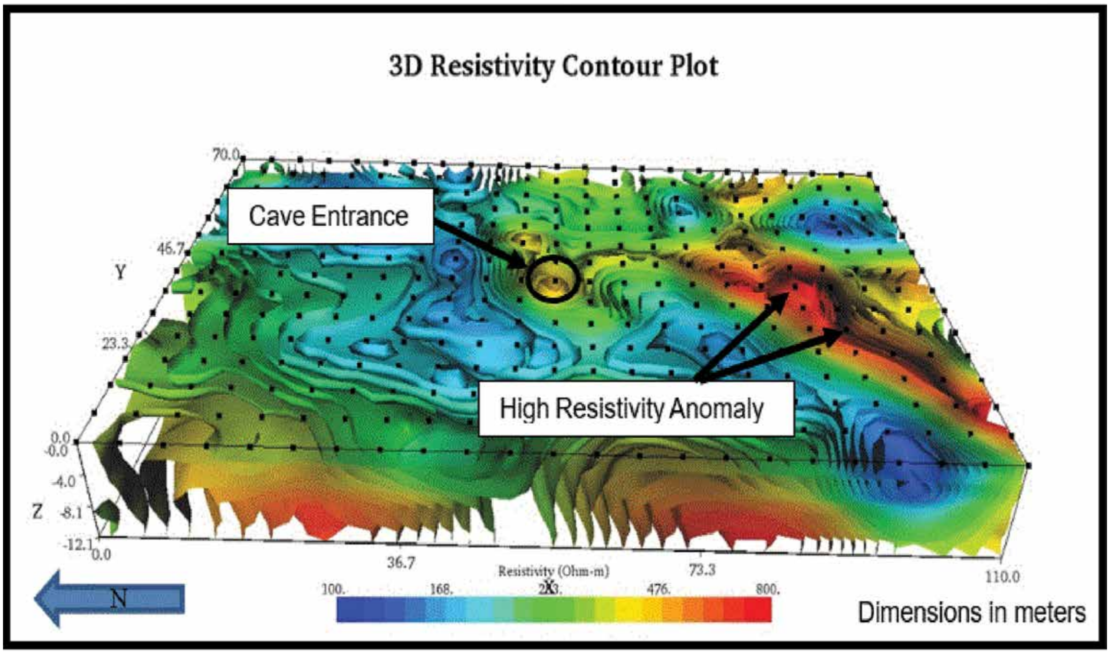

Figure 4. Resistivity contours illustrate the Friesenhahn Cave area. Black dots represent electrode placements and are five meters apart.

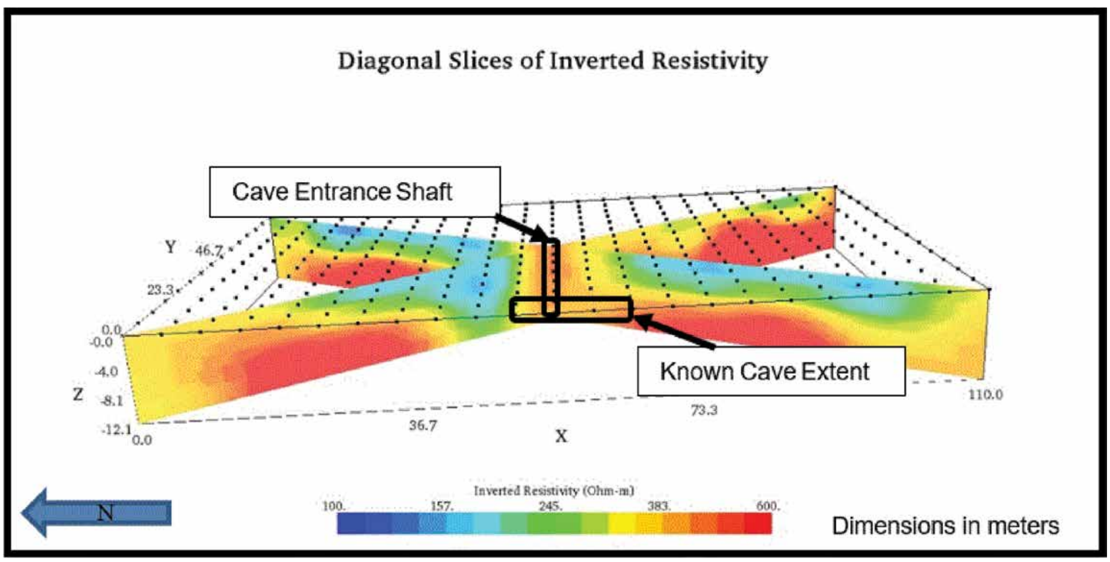

Figure 5. Diagonal cross-section vertex through the center of the cave shaft entrance.

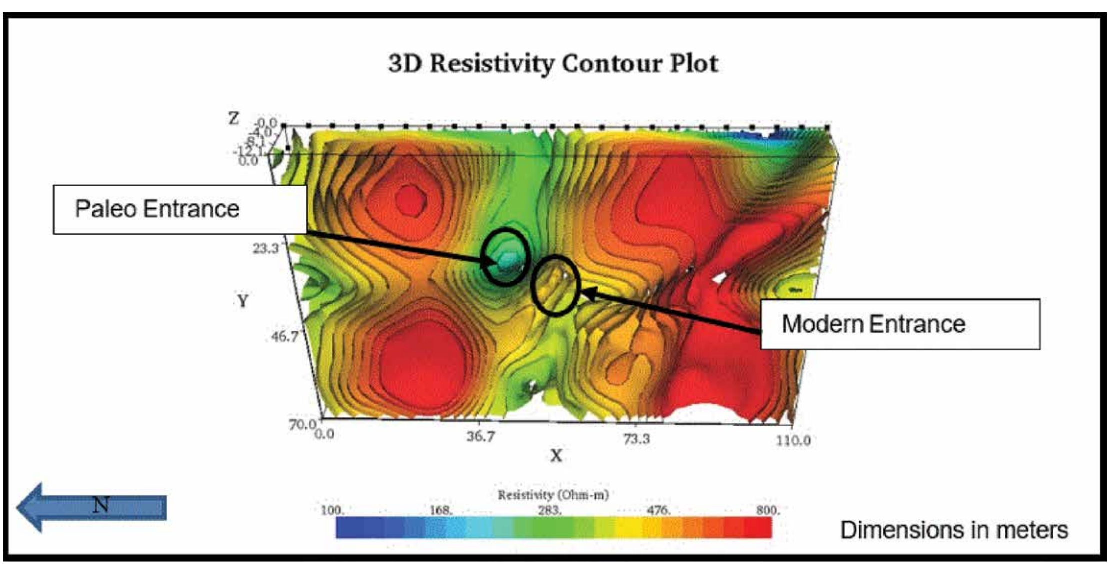

Figure 6. View from underneath revealing both Paleo and modern entrances.

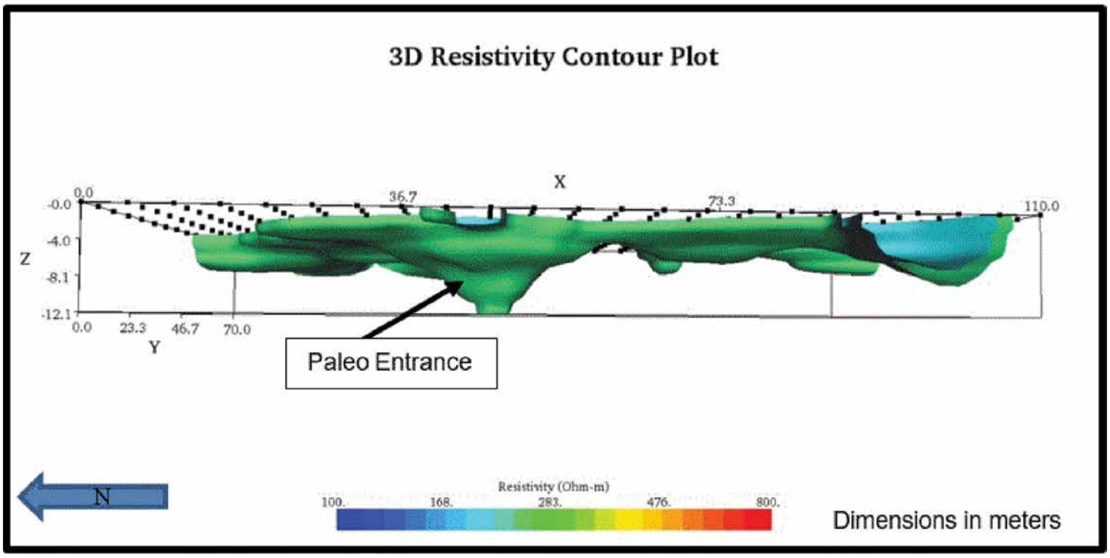

Figure 7. With resistivity values for the modern cave entrance removed, the Paleo entrance is evident.

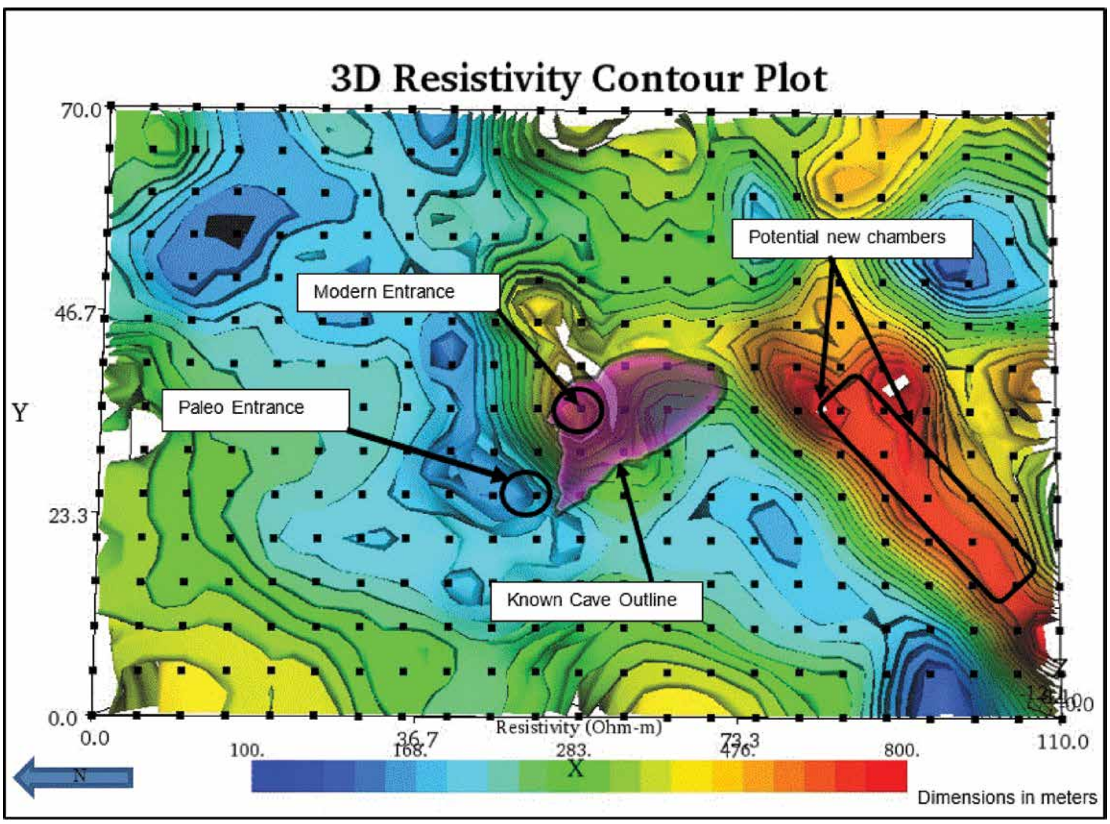

Figure 8. Top view, Cave in center magenta overlay, Paleo entrance left of center, and interpreted new chamber to right center.

Results and Discussion

Three-dimensional electrical resistivity results are provided in the following illustrations. They graphically show the electrical properties of the subsurface around Friesenhahn Cave. The models of inverted resistivity for the dipole-dipole data are illustrated as two-dimensional cross-sections, and three-dimensional block diagrams. Resistivity values range from approximately 100 to 800 ohm-m.

Located in the center of the grid in Figure 4, the known cave entrance indicates moderately high resistivity (i.e., yellow at approximately 350-400 ohm-m). The surface is shown to have relatively low resistivity (i.e., blue and green at less than approximately 250 ohm-m), with an exception of a NE-SW-trending zone from near the cave entrance (yellow) to the SW of the survey grid, which has electrical resistivity in excess of 500 ohm-m (orange), and as high as 800 ohm-m (red).

Two intersecting vertical cross-sections of electrical resistivity values are illustrated in Figure 5. The two vertical cross-sections are centered over the cave entrance. The entrance shaft is illustrated in orange with a resistivity of approximately 375 ohm-m. Relatively high electrical resistivity (i.e., approximately 400 ohm-m and higher, orange and red) may indicate undefined karst conduits. These interpretations suggest that void spaces correlate with high electrical resistivity. This is consistent with the known, modern cave entrance and the absence of clay materials on the interior walls of either the cave entrance or the main cave chamber.

Figure 6 is a bottom view of the resistivity results with North to the left. The center of the grid is the base of the cave shaft entrance with a resistivity value of approximately 400 ohm-m. Electrical resistivity in excess of 500 ohm-m is evident elsewhere at the bottom of the block diagram.

Resistivity contours within the block diagram with values of 175−250 ohm-m are illustrated in Figure 7. Resistivity contours outside that range have been removed from this image to obscure the modern entrance. The resultant image reveals only the Paleo entrance, located approximately 10 m NW of the modern entrance. These relatively low electrical resistivity zones are interpreted as the collapsed entrance, once used by animals to access the cave during the Pleistocene Period (paleo-entrance). A debris-filled depression currently exists on the surface and marks the entrance to the collapsed feature. The collapse is evident within the cave as well, and it contains abundant fossil remains.

Figure 8 is a top view of the resistivity plot with the cave entrance at the center and the extent of the known cave illustrated in magenta. Clearly visible in the resistivity plot is a potential passage extending from near the known cave chamber, seen at the center of the grid in yellow, extending south (to the right in this image) approximately 20 m, then encountering a significantly higher resistivity zone, as high as 800 Ohm-m, represented in red. Significant volumes of water have been observed flowing into Friesenhahn Cave and passing through undefined karst conduit.

This geophysical analysis used dipole-dipole measures in a 110 m by 55 m grid centered on the entrance shaft of Friesenhahn Cave in northern Bexar County Texas with five-meter electrode spacing. The ground moisture level was very high; probably near saturation, as it had been raining heavily for several days, right up to the morning of the data collection. The cave itself was thoroughly soaked with water running down the walls and ceiling.

Conclusions

The three-dimensional electrical resistivity survey completed at Friesenhahn Cave, using dipole-dipole array, revealed significant potential open voids as yet unseen and unconfirmed. It is expected that the next step in Friesenhahn research will include confirmation of this interpretation by drilling the most probable voids associated with the cave system. With the strength of the data, confidence is high that the interpretation is correct and will lead to discovery of more cave passages.

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